

Characterization of Cold Sprayed CuCrAl-Coated and Uncoated GRCop-84 Substrates for Space Launch Vehicles

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Abstract

A newly developed Cu-23(wt.%)Cr-5%Al (CuCrAl) alloy is currently being considered as a protective coating for GRCop-84 (Cu-8(at.%)Cr-4%Nb). The coating was deposited on GRCop-84 substrates by the cold spray deposition technique. Cyclic oxidation tests conducted in air on both coated and uncoated substrates between 773 and 1073 K revealed that the coating remained intact and protected the substrate up to 1073 K. No significant weight loss of the coated specimens were observed at 773 and 873 K even after a cumulative cyclic time of 500 h. In contrast, the uncoated substrate lost as much as 80% of its original weight under similar test conditions. Low cycle fatigue tests revealed that the fatigue lives of thinly coated GRCop-84 specimens were similar to the uncoated specimens within the limits of experimental scatter. It is concluded that the cold sprayed CuCrAl coating is suitable for protecting GRCop-84 substrates.

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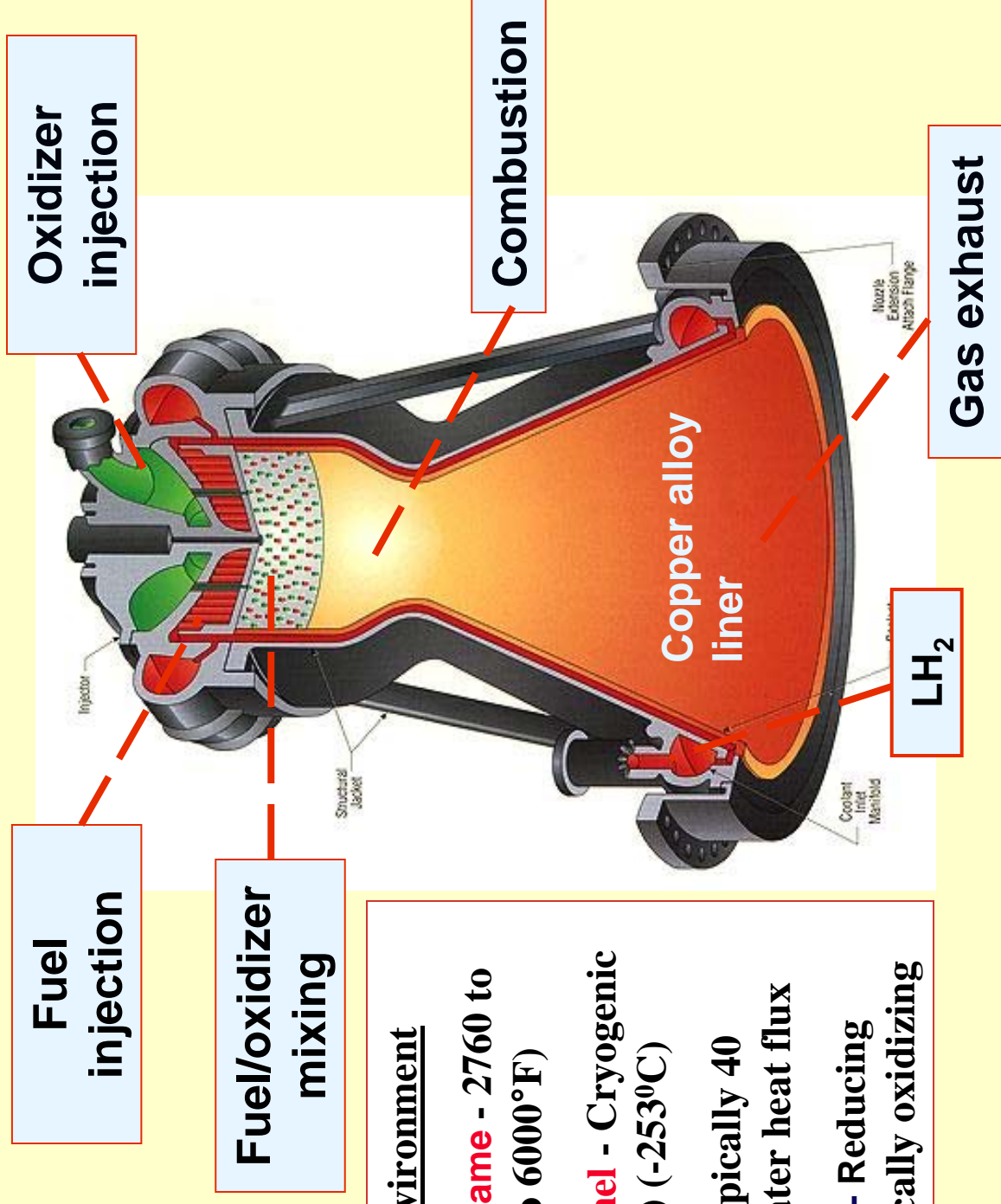
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@ Retired # Deceased

**TMS Annual Meeting,
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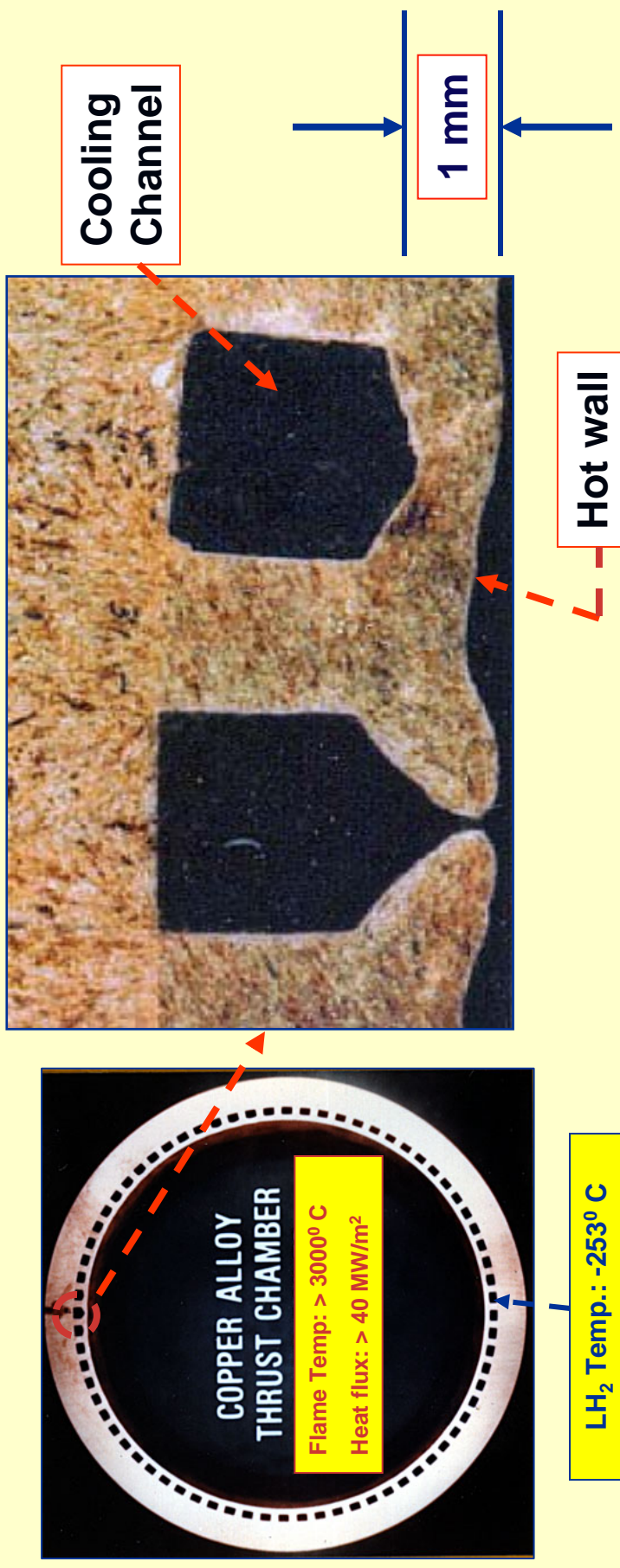
Schematic of a LH₂/LOX Rocket Engine



Operating Environment

- **Combustion flame** - 2760 to 3315°C (5000 to 6000°F)
- **Cooling channel** - Cryogenic hydrogen (LH₂) (-253°C)
- **Heat Flux** - Typically 40 MW/m² or greater heat flux
- **Environment** - Reducing (overall) but locally oxidizing

“Dog House” Failure of Combustion Chamber Liners

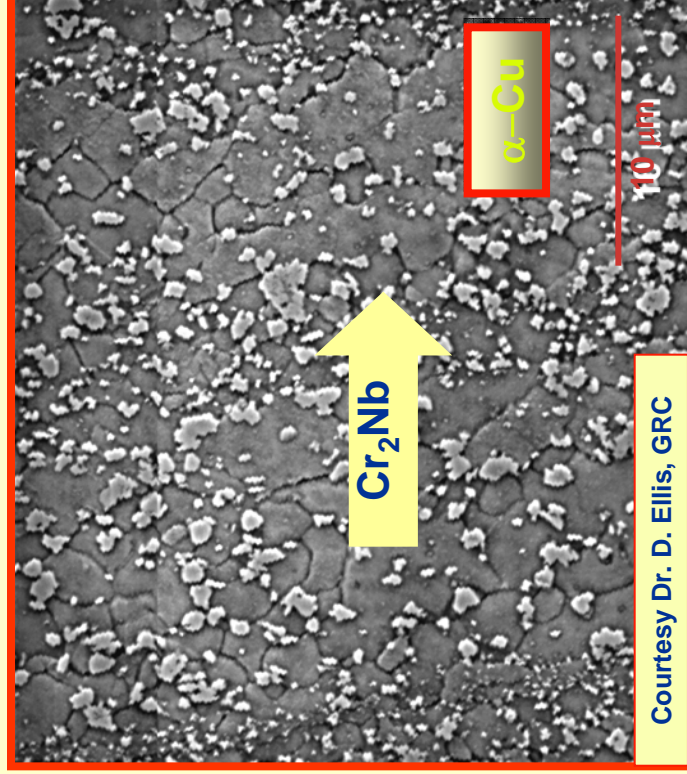


- Failure of the liner occurs by a complex combination of creep, low cycle fatigue, thermal ratcheting and environmental interaction (“blanching”)

GRCop-84 (Cu-8%Cr-4%Nb) Microstructures and

Potential Applications

Microstructure of Extruded GRCop-84

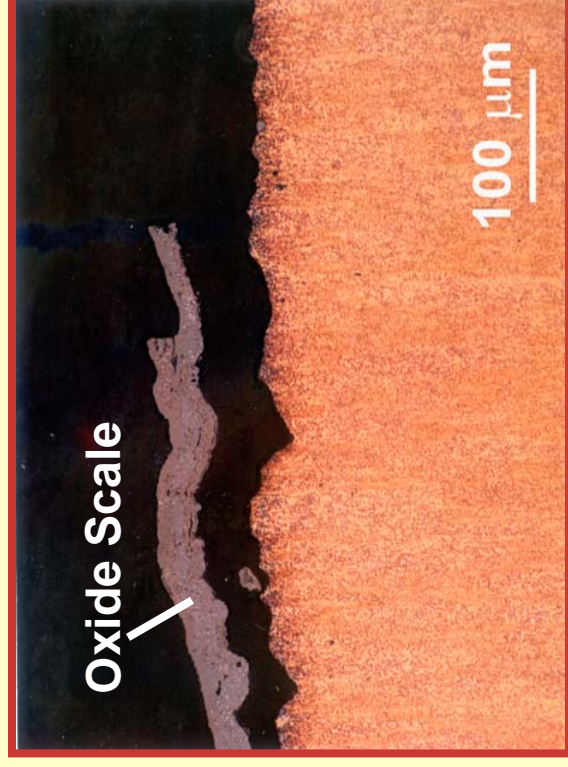


- Excellent mechanical properties
- Good oxidation resistance relative to most commercial copper alloys

- Reusable Launch Vehicles (RLVs) - Combustor liners and nozzles

Oxide Scale Spallation in Cyclically Oxidized GRCop-84 in Air at 773 K After 1000 Cycles

Optical Micrograph



Back Scattered Electron Image



30 minutes at temperature followed by a 5 minute cool down

- GRCop-84 forms a non-adherent oxide scale which limits engine operating temperatures and complicates engine design

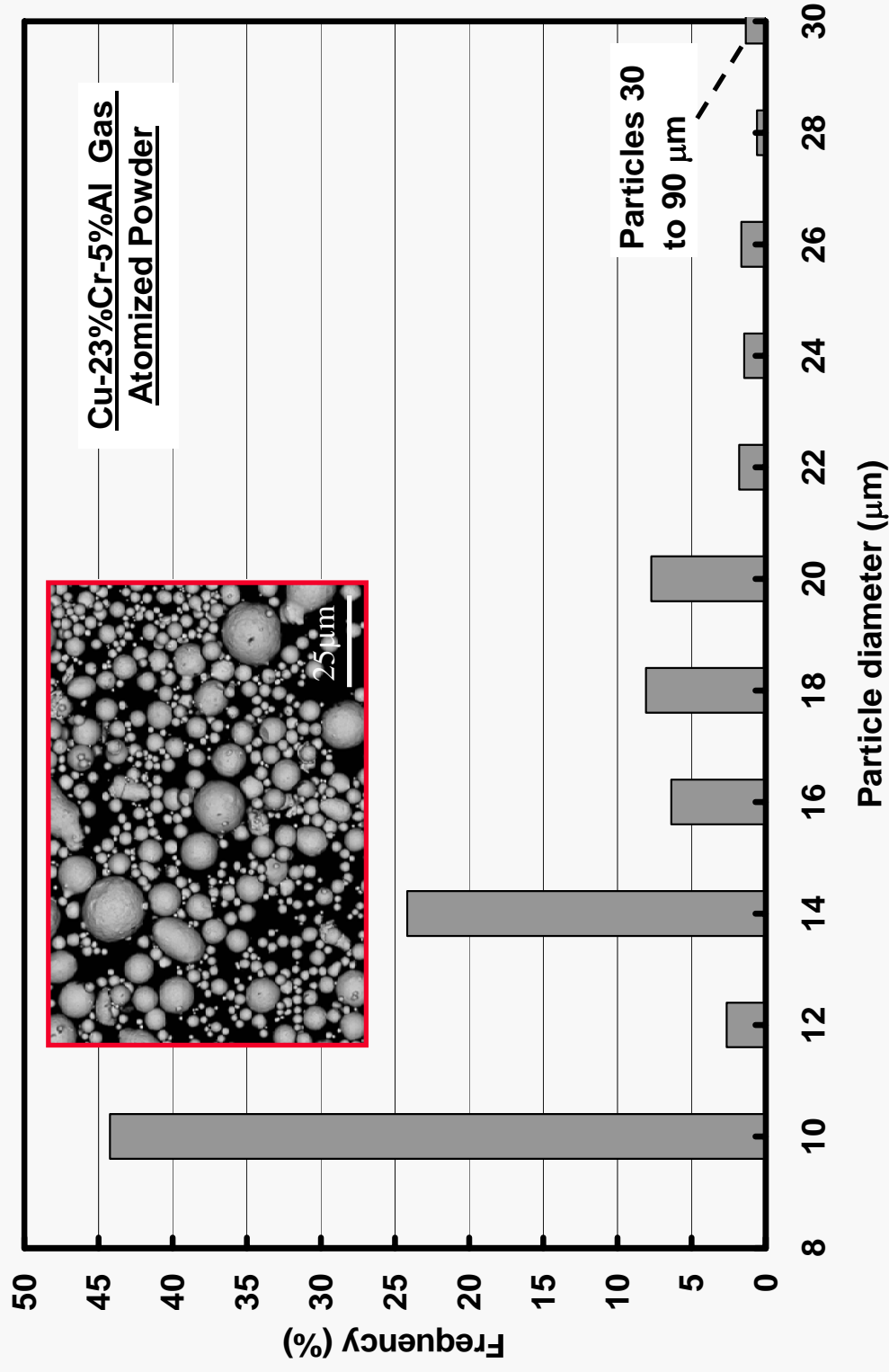
Top Coat Compositions and Thermal Conductivities

<u>Material</u>	<u>Thermal Conductivity</u> <u>(W/m/K)</u>
GRCop-84 (Substrate)	315
Cu-26%Cr (Rocketdyne – NASP)	285
Cu-23%Cr-5%Al (NASA – Third Generation Reusable Launch Vehicle)	170
NiAl (Aeronautics)	55
NiCrAlY (Aeronautics)	25

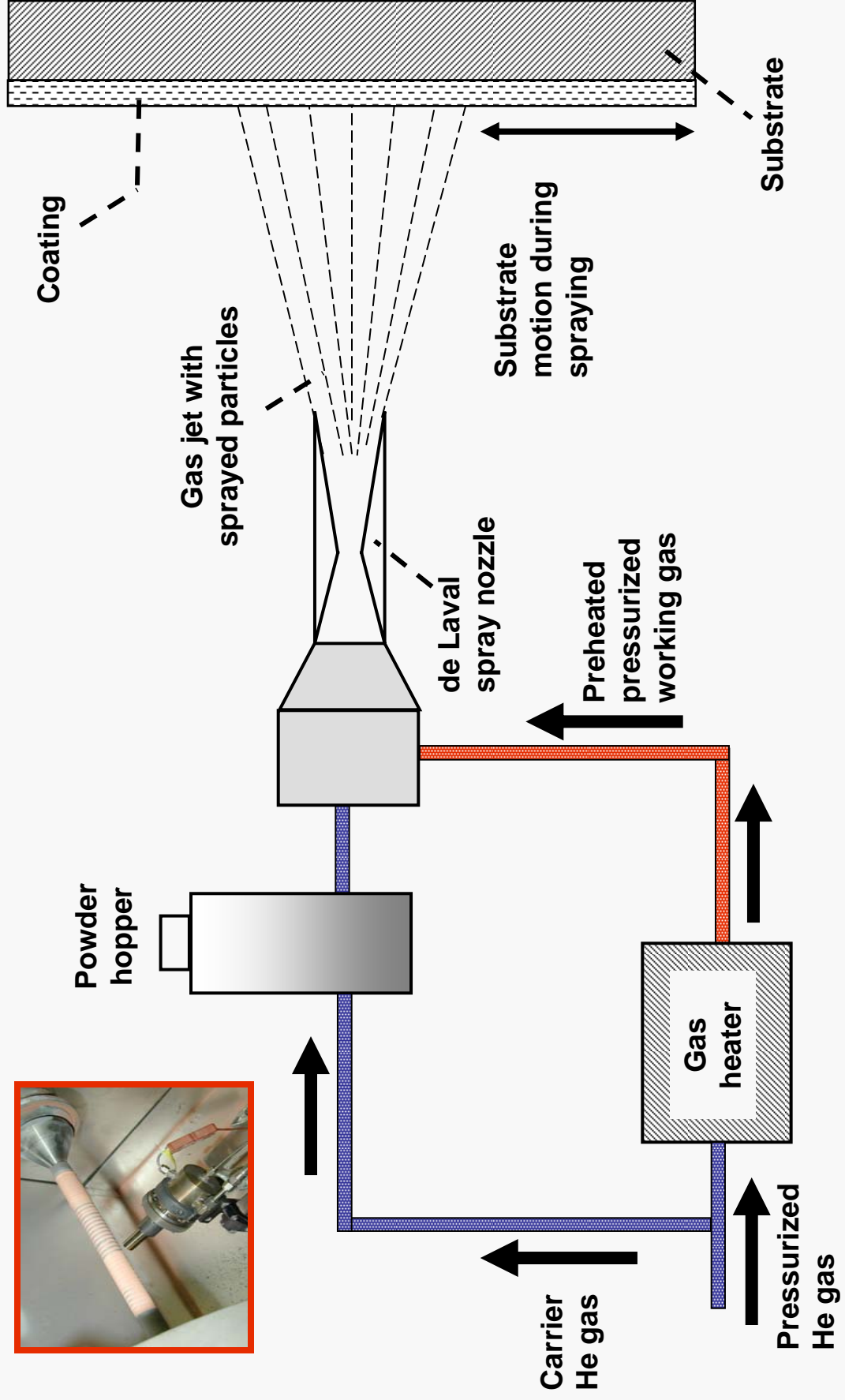
Objectives

Preliminary evaluation of the thermal cyclic and low cycle fatigue behavior of newly developed Cu-23%Cr-5%Al overlay coatings for GRCop-84 substrates

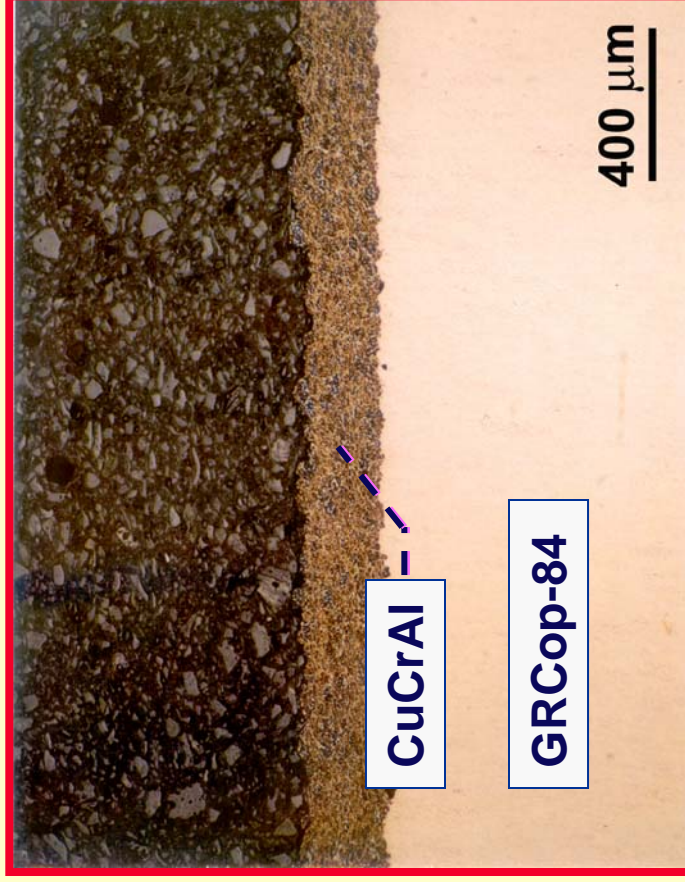
Powder Particle Size Distribution



Cold Spray Process

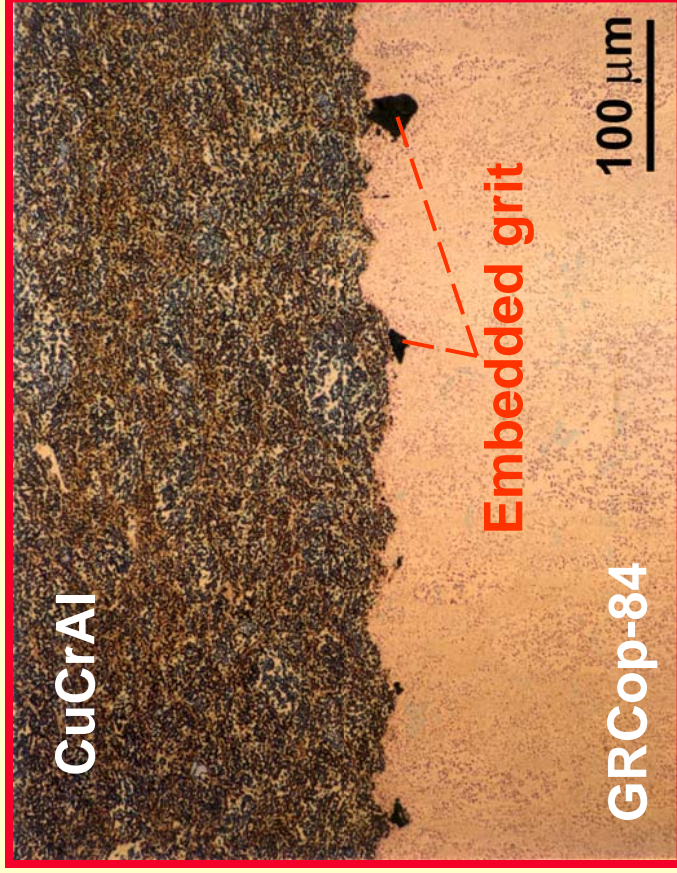


Coating Microstructures



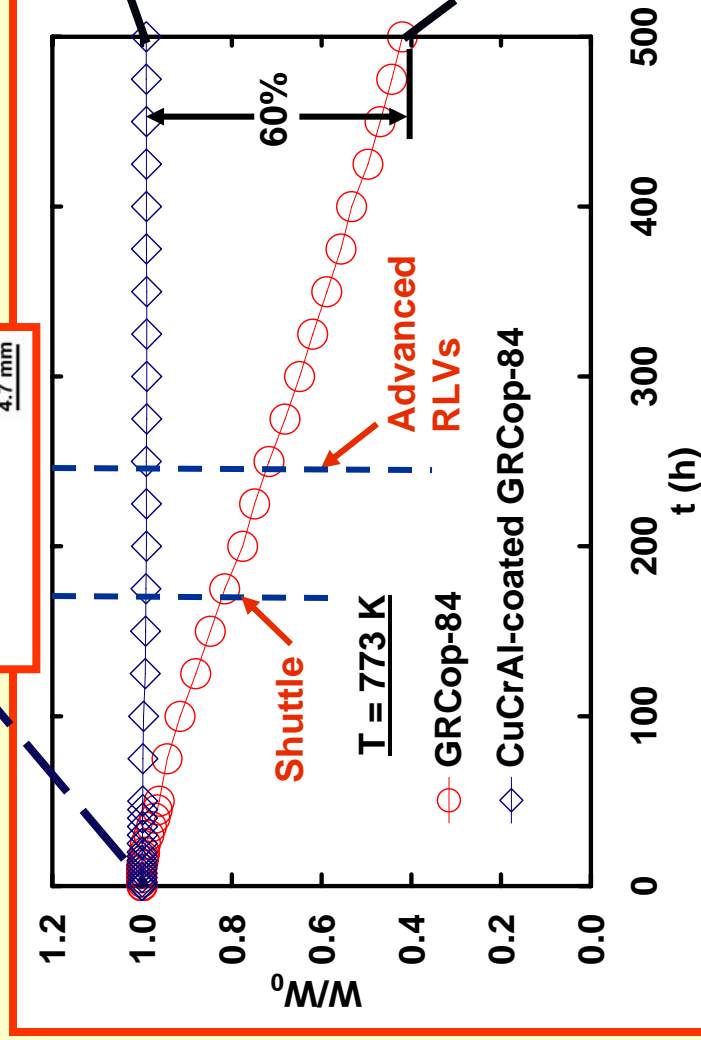
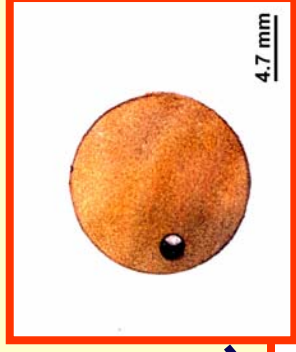
- Dense coatings generally free of cracks and voids

Processing Defects



- Embedded grit particles were commonly observed
- Cracks and porosity in the coating were observed in some instances
- Non-uniform coating thickness (e.g. LCF specimens)

Thermal Cycling of Cold-Sprayed CuCrAl Coated and Uncoated GRCop-84 Specimens in Air at 773 K

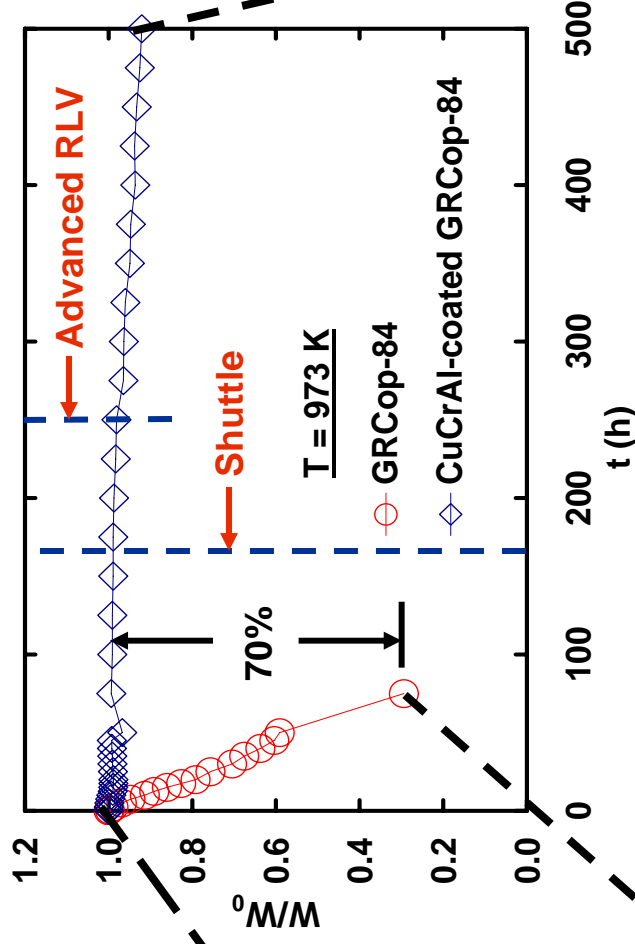


- 30 minutes at temperature followed by a 5 minute natural cool down

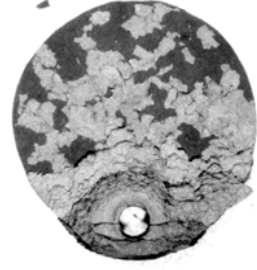
Thermal Cycling of Cold-Sprayed CuCrAl Coated and Uncoated GRCop-84

Specimens in Air at 973 K

- 30 minutes at temperature followed by a 5 minute natural cool down



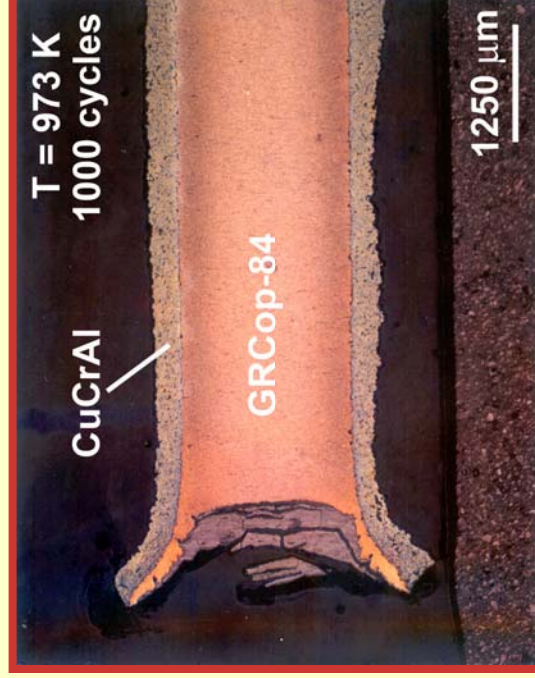
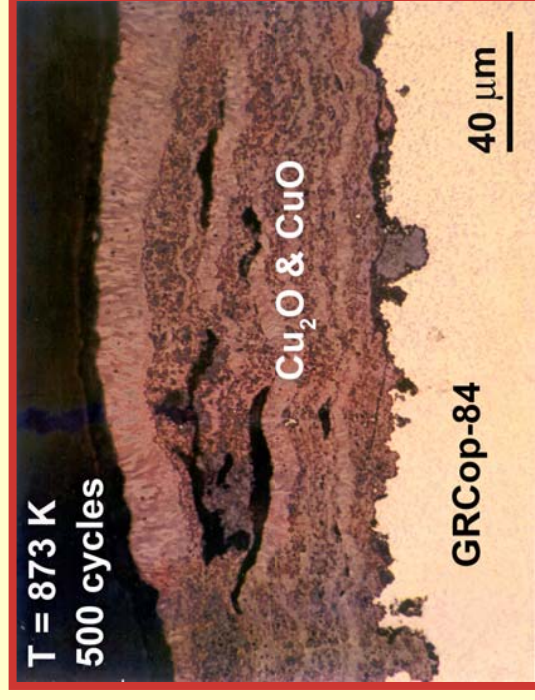
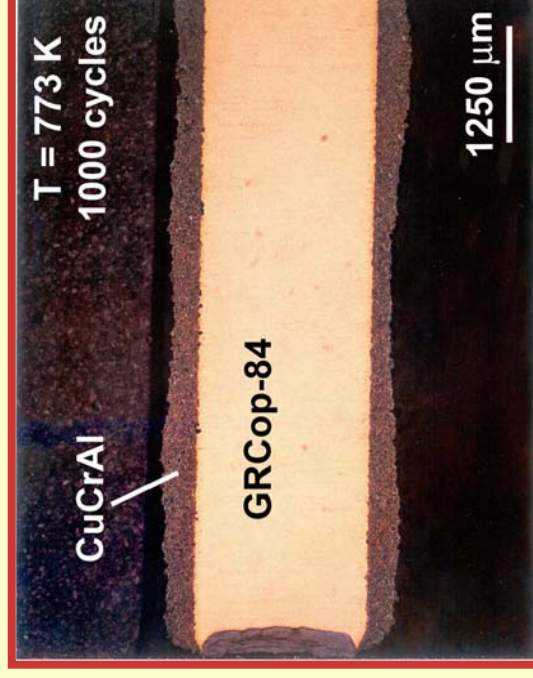
150 cycles



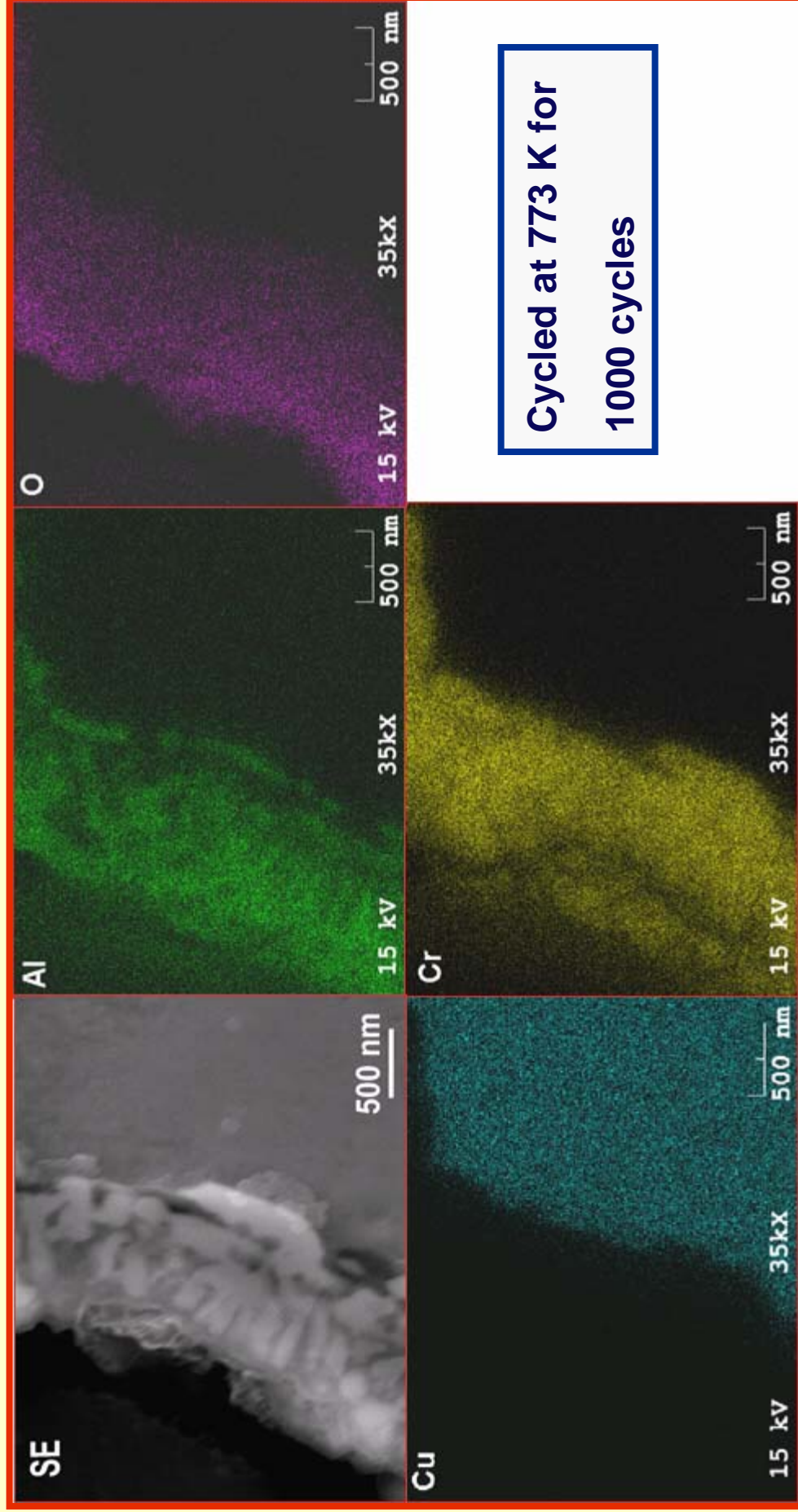
1000 cycles



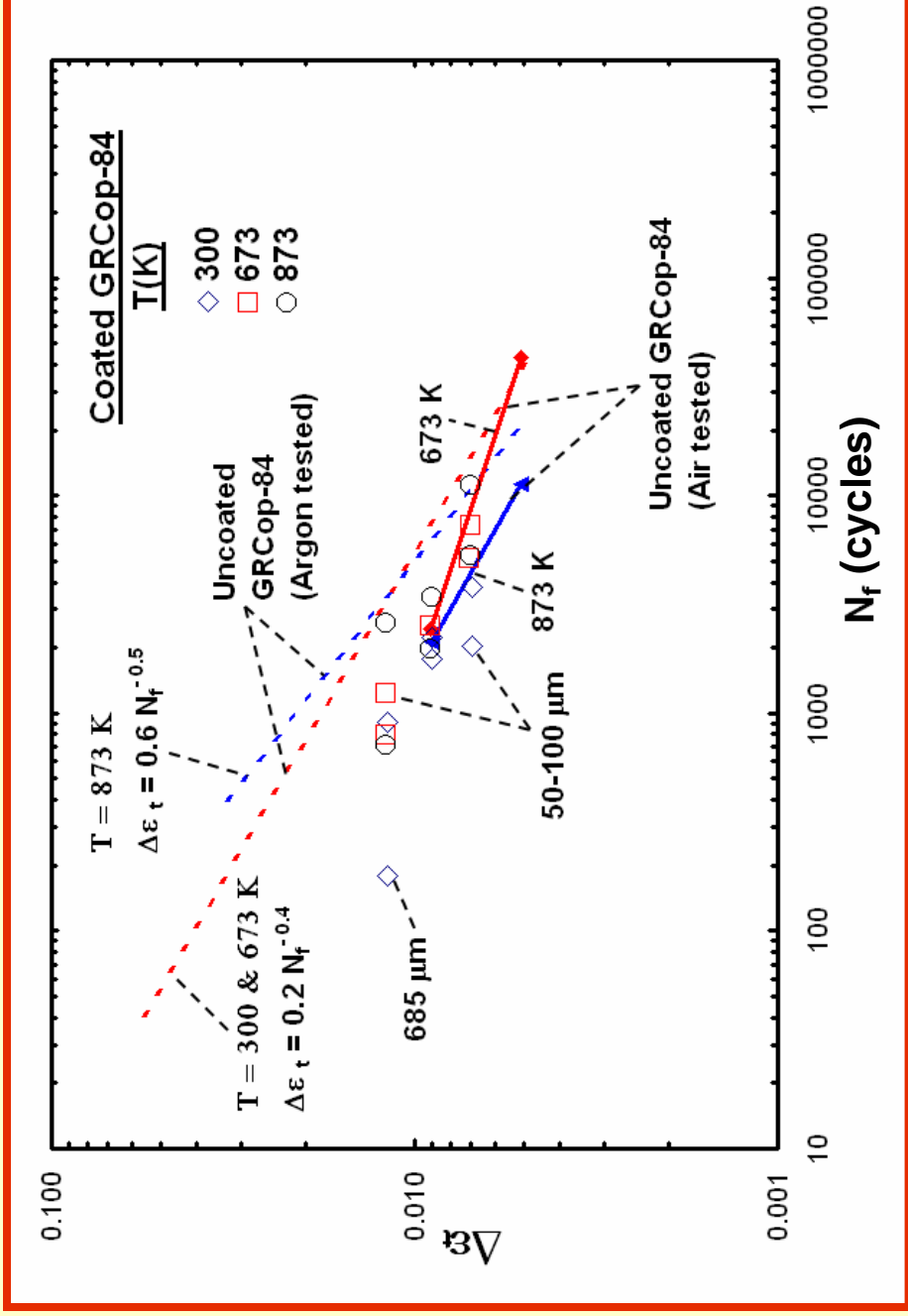
Cross-Sectional Microstructures



X-ray dot maps of oxidized Cu-23%Cr-5%Al coating



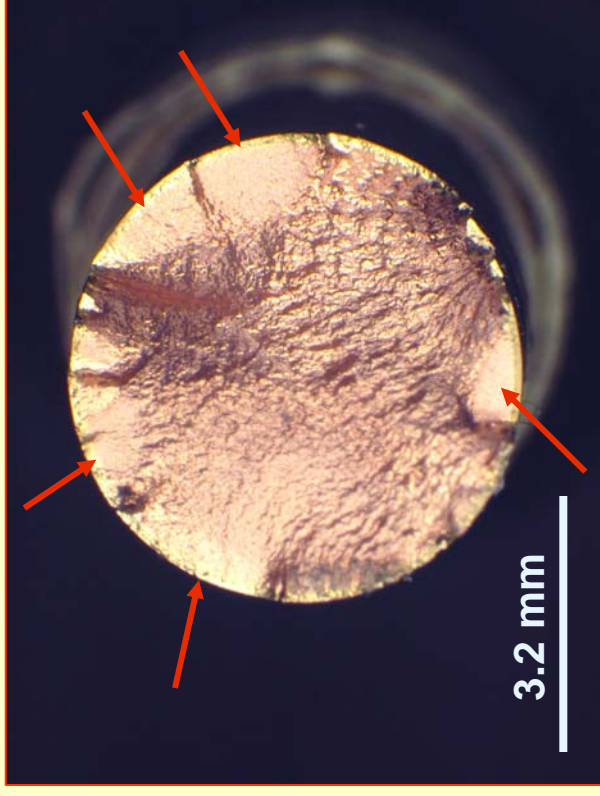
Low Cycle Fatigue Properties of Coated and Uncoated Extruded GRCop-84



- Coated specimens exhibit either comparable or lower fatigue lives than uncoated specimens within factors of 2 to 5
- LCF life appears to decrease with increasing coating thickness

Fractograph of a CuCrAl-Coated GRCo-84

LCF Specimen



Test conditions

Specimen: 2T-10

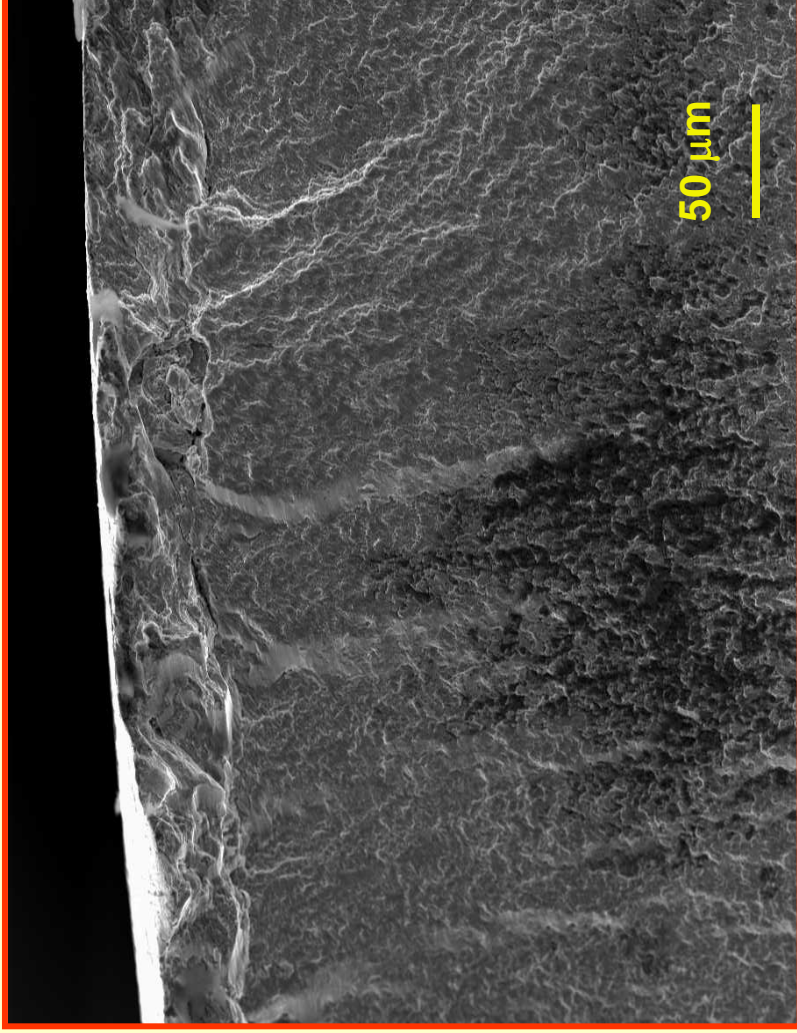
Coating thickness = 100 μm

Air, 300 K

Strain range = 1.2%

Life = 910 cycles

Fractograph of a CuCrAl-Coated GRCo-84 LCF Specimen



Test conditions

Specimen: 2T-15

Coating thickness = 55 μm

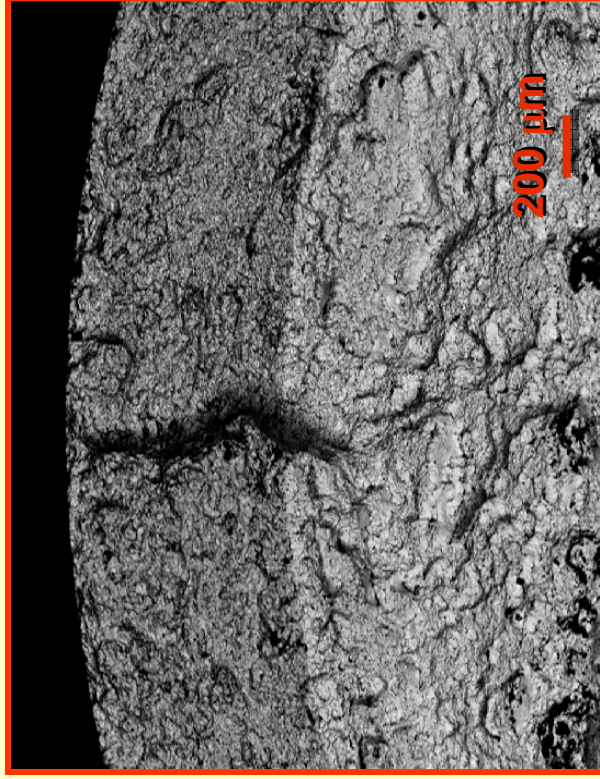
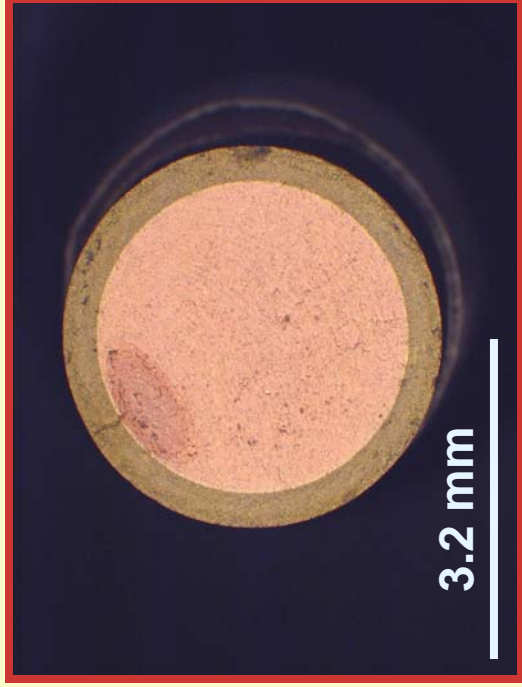
Strain range = 0.7%

Life = 2042 cycles

- No coating delamination was observed in the observed specimens
- All cracks initiated either at the free surface or in the GRCo-84 matrix

Fractographs of a CuCrAl-Coated GRCo-84

LCF Specimen



Test conditions

Specimen: 2T-3

Coating thickness = 685 μm

Air, 300 K

Strain range = 1.2%

Life = 178 cycles

Summary and Conclusions

- A new CuCrAl coating alloy was successfully cold spray deposited on GRCop-84 substrates.
- Thermal cyclic tests were conducted between 773 and 973 K
 - Coated specimens exhibited negligible loss in weight compared to the uncoated specimens
- Low cycle fatigue (LCF) tests were conducted between 300 and 873 K
 - Fatigue lives of the coated specimens were comparable to the uncoated specimens within the limits of experimental scatter
 - No coating delamination.